



جامعة مولاي إسماعيل
Université MOULAY ISMAÏL



Advanced biomedical signal and image processing

Master: Plasturgia & Biomedical Engineering

2025-2026

Faculté de Science Meknes

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Section 3 : Processing of Biomedical Images

General Introduction

Chapter 1: X-ray

Chapter 2. Magnetic resonance imaging (MRI)

Chapter 3. Ultrasound imaging

Chapter 4. Nuclear medicine

Chapter 5. Optical imaging

General introduction

Techniques and processes used to create visual representations of the interior of a body:

- **Clinical analysis**
- **Medical intervention**
- **Visualizing the functions of some organs or tissues.**
- **Allows physicians to see inside the body without surgery**

General introduction

Importance in Medicine

Plays a crucial role in modern healthcare:

by providing critical insights that are essential for

- Diagnose conditions
- Guide interventions
- Monitor disease progression
- Preventative care



General introduction

Medical Imaging is evolving with the advanced technology and IT.

- **X-rays (1895):** Wilhelm Conrad Roentgen's discovery of X-rays marked the beginning of medical imaging, allowing the visualization of bones and certain internal organs.
- **Ultrasound (1940s-1950s):** The development of ultrasound technology provided a non-invasive method for visualizing soft tissues, particularly useful in obstetrics and cardiology.
- **Computed Tomography (CT) (1970s):** The advent of CT scanning introduced cross-sectional imaging, enhancing the ability to detect and characterize complex conditions.

General introduction

History

- **Magnetic Resonance Imaging (1980s):** MRI revolutionized imaging by offering high-resolution images of soft tissues without ionizing radiation, expanding diagnostic capabilities in neurology, orthopedics, and oncology.
- **Nuclear Medicine (1950s-present):** Techniques like PET and SPECT emerged; enabling functional imaging that visualizes physiological processes at the molecular level.
- **Recent Advances:** Ongoing innovations, such as functional MRI, hybrid imaging techniques (e.g., PET/CT, PET/MRI), and the integration of AI artificial intelligence, continue to push the boundaries of medical imaging.

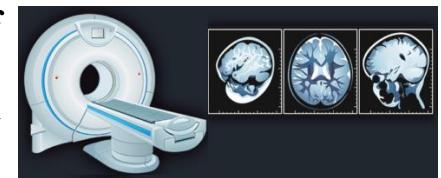
General introduction

The common Imaging Modalities :

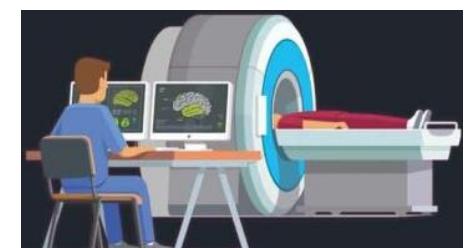
X-ray (Traditional imaging modality that uses ionizing radiation to produce images of bones and certain tissues)



Computed Tomography (CT, more advanced form of X-ray that produces cross-sectional images of the body using multiple X-ray images combined by a computer)



Magnetic Resonance Imaging (MRI, uses powerful magnets and radio waves to produce detailed images of soft tissues, such as the brain, spinal cord, and muscles)

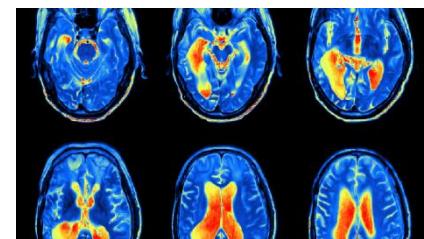


General introduction

Ultrasound (Employs high-frequency sound waves to produce images of soft tissues and is commonly used in obstetrics and cardiology)



Nuclear Medicine (e.g., PET, SPECT, uses small amounts of radioactive materials to diagnose and treat diseases by visualizing metabolic processes)



Optical Imaging (Involves the use of light, typically near-infrared, to image tissues, particularly for brain and skin imaging).

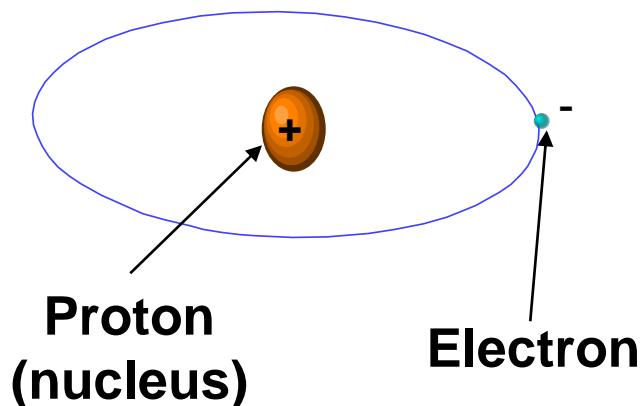


General introduction

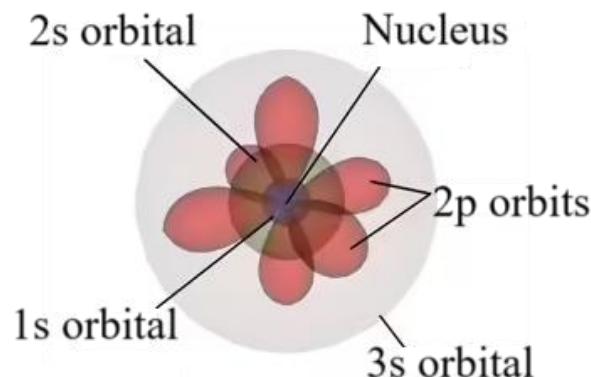
Fundamental physics of radiation

Models of Atoms

Bohr Model



Quantum Mechanical Model of Electron Orbitals

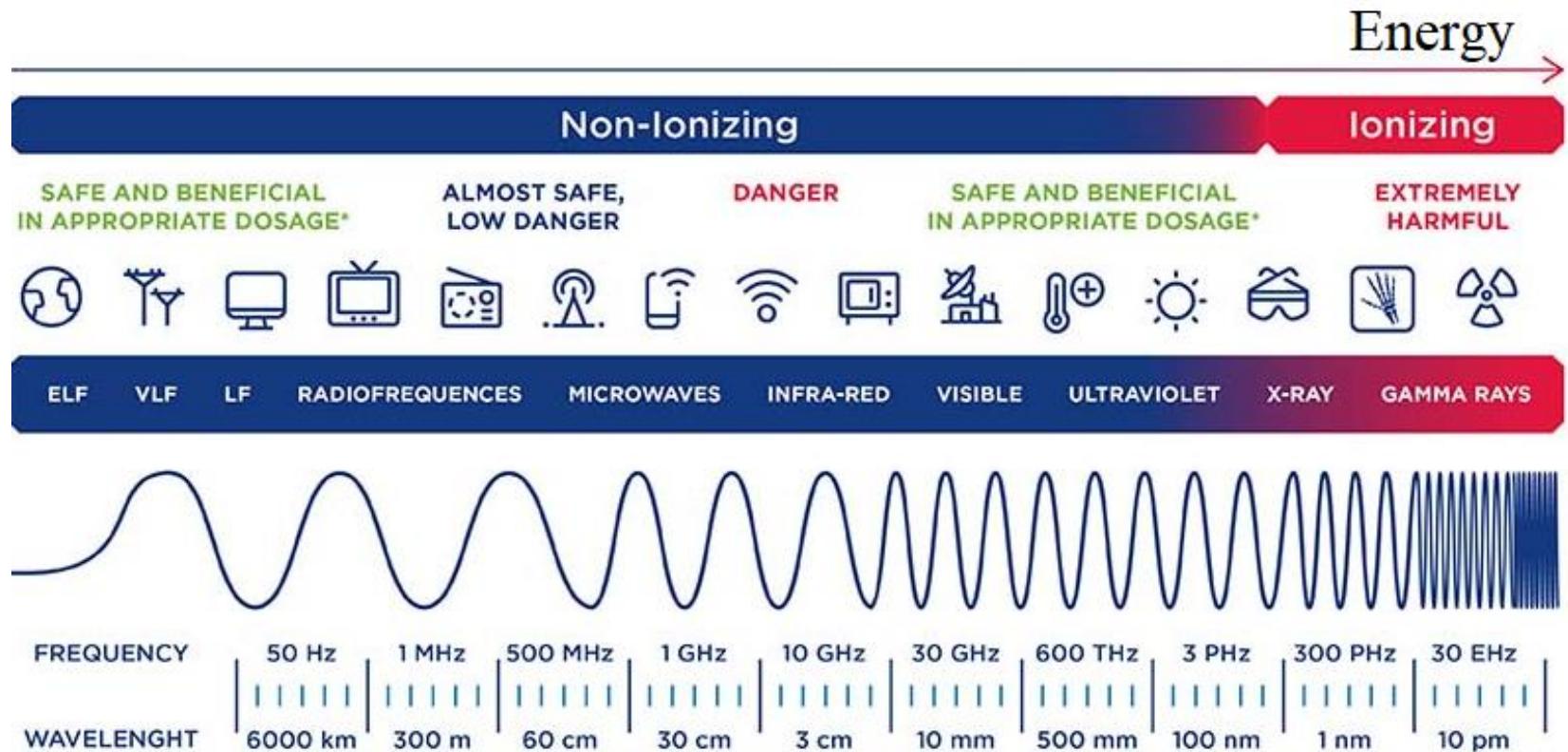


Electron orbits nucleus $\sim 10^{15}$ times per second

General introduction

Fundamental physics of radiation

Radiation



General introduction

Exercise 1

Find the following:

(a) Maximum frequency

(b) minimum wavelength of X-rays produced by 30 kV electrons.

Electron potential, $V = 30 \text{ kV} = 3 \times 10^4 \text{ V}$

electron energy, $E = 3 \times 10^4 \text{ eV}$

$e = 1.6 \times 10^{-19} \text{ C}$

(a) Maximum frequency by the X-rays = ν (b) minimum wavelength produced

$E = h\nu$ energy of the electrons

$h = \text{Planck's constant} = 6.626 \times 10^{-34} \text{ Js}$

$$\lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{7.24 \times 10^{18}}$$

$$= 4.14 \times 10^{-11} \text{ m}$$

$$= 0.0414 \text{ nm}$$

$$\nu = \frac{E}{h} = \frac{1.6 \times 10^{-19} \times 3 \times 10^4}{6.626 \times 10^{-34}} = 7.24 \times 10^{18} \text{ Hz}$$

General introduction

Exercise 2

Monochromatic light of wavelength 632.8 nm is produced by a helium-neon laser. The power emitted is 9.42 mW.

- (a) Find the energy and momentum of each photon in the light beam.
- (b) How many photons per second, on average, arrive at a target irradiated by this beam? (Assume the beam to have a uniform cross-section which is less than the target area)
- (c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

General introduction

Exercise 2

Monochromatic light having a wavelength, $\lambda = 632.8 \text{ nm} = 632.8 \times 10^{-9} \text{ m}$

Given that the laser emits the power of, $P = 9.42 \text{ mW} = 9.42 \times 10^{-3} \text{ W}$

Planck's constant, $\mathbf{h = 6.626 \times 10^{-34} Js}$

Speed of light, $\mathbf{c = 3 \times 10^8 \text{ m/s}}$

Mass of a hydrogen atom, $\mathbf{m = 1.66 \times 10^{-27} \text{ kg}}$

General introduction

Exercise 2

a) The energy of a photon is given by: $E=hc/\lambda$ Where:

h is Planck's constant ($6.626 \times 10^{-34} \text{ J} \cdot \text{s}$)

c is the speed of light ($3 \times 10^8 \text{ m/s}$)

λ is the wavelength (632.8 nm)

$$E = E = 3.14 \times 10^{-19} \text{ J}$$

The momentum of a photon is given by the de Broglie wavelength formula:

$$p = h/\lambda$$

we get:

$$p = 1.05 \times 10^{-27} \text{ kg} \cdot \text{m/s}$$

General introduction

Exercise 2

b) The power of the laser is $W = 9.42 \times 10^{-3}$. The energy of each photon is $3.14 \times 10^{-19} J$

The number of photons per second is:

$$\frac{Power}{Energy/photon} = 3 \times 10^{15}$$

General introduction

Exercise 2

c) How fast does a hydrogen atom have to travel in order to have the same momentum as that of the photon?

The momentum of the photon is $1.05 \times 10^{-27} \text{ kg} \cdot \text{m/s}$. The mass of a hydrogen atom is $1.67 \times 10^{-27} \text{ kg}$.

Using the formula for momentum, $p = mv$, we can solve for the velocity:

$$v = p/m = 6.3 \times 10^5 \text{ m/s}$$

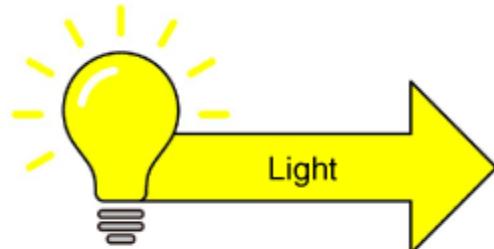
So a hydrogen atom would need to travel at 630,000 m/s to have the same momentum as the photon.

General introduction

Fundamental physics of radiation

Radioactive vs. Radiation

Visible light



Lumen (lm) or Watt(W)



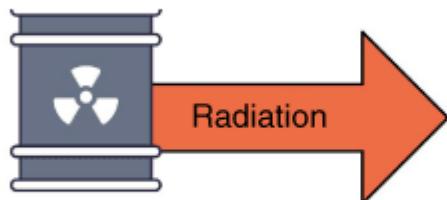
Joule(J)

the light hits you and warms you up

lux(lx)

the amount of light that hits an object (the amount of light you perceive as brightness)

Radioactive material



Becquerel(Bq)

Amount of radiation



Gray(Gy)

amount of energy given off by radiation

Sievert(Sv)

the amount of radiation a person receives (is exposed to).

Fundamental physics of radiation

Radioactive vs. Radiation

Radiation flow definition

Any light beam carries radiant energy (In particular a monochromatic radiation such as a laser beam).

The energy flow is the ratio between the energy transported and the time taken to transport it.

It is therefore a power of radiation, expressed in Watt.

Exercise

A spot lamp concentrates all the light from a bulb of intensity $I = 100 \text{ cd}$ in a circle of radius $R = 1 \text{ m}$ on a wall. The light beam is perpendicular to the wall. Calculate the average illuminance E produced. The Source emits light in all directions of space $I = \text{Cte} = 100 \text{ cd}$

General introduction

Fundamental physics of radiation

Radioactive vs. Radiation

To calculate the average illuminance E produced by the spot lamp on the wall, we need to use the formula for illuminance:

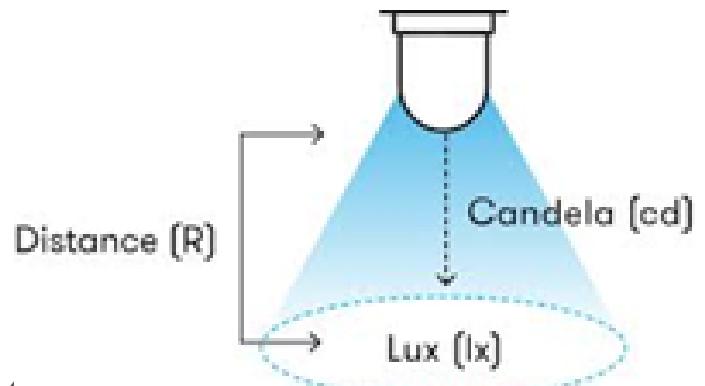
$$E = \frac{I}{A}$$

Where:

E is the illuminance (in lux or lumens/m²)

I is the luminous intensity of the light source (in candelas or lumens/steradian)

A is the area of the illuminated surface (in m²)



General introduction

Fundamental physics of radiation

Radioactive vs. Radiation

Given information:

Luminous intensity of the light source, $I = 100 \text{ cd}$

Radius of the illuminated circle on the wall, $R = 1 \text{ m}$

First, we need to calculate the area of the illuminated circle on the wall:

$$A = \pi R^2 = \pi (1 \text{ m})^2 = \pi \text{ m}^2$$

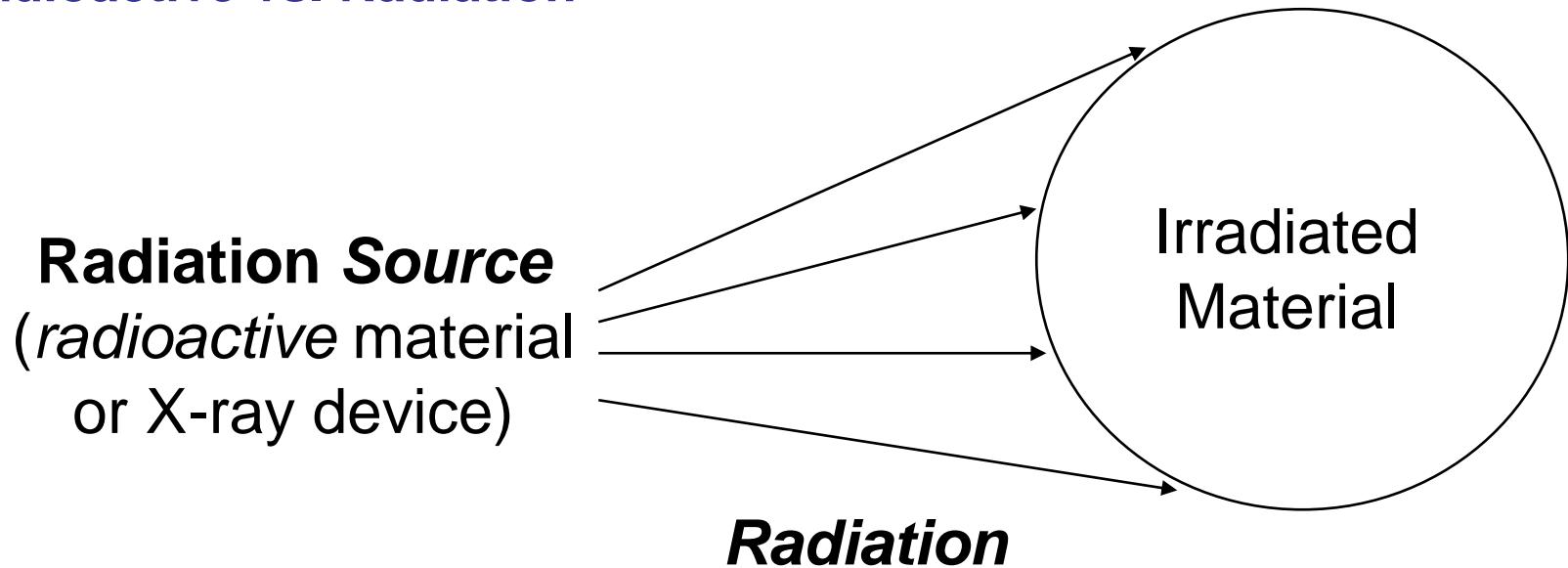
Now we can calculate the illuminance E :

$$E \approx 31.83 \text{ lux}$$

General introduction

Fundamental physics of radiation

Radioactive vs. Radiation



General introduction

Major types of radioactivity depend on chemical equations:

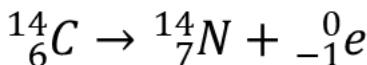
alpha decay

Uranium – 238 → Thorium – 234 + α particle



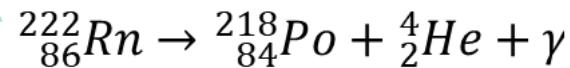
beta decay

Carbon – 14 → Nitrogen – 14 + β – particle + $\bar{\nu}$ (Antineutrino)



gamma ray

Excited nucleus → Stable nucleus + γ photon



General introduction

Fundamental physics of radiation

Nuclide vs. Radionuclide

- **Nuclide** - general term referring to any known isotope, whether stable (about 290) or unstable (about 2200), of any chemical element
- **Radionuclide** - a radioactive nuclide

Nuclide Designation:

$${}_{\text{Z}}^{\text{A}} \text{X}$$

A atomic mass (no. protons + no. neutrons)

Z atomic number (number of protons)

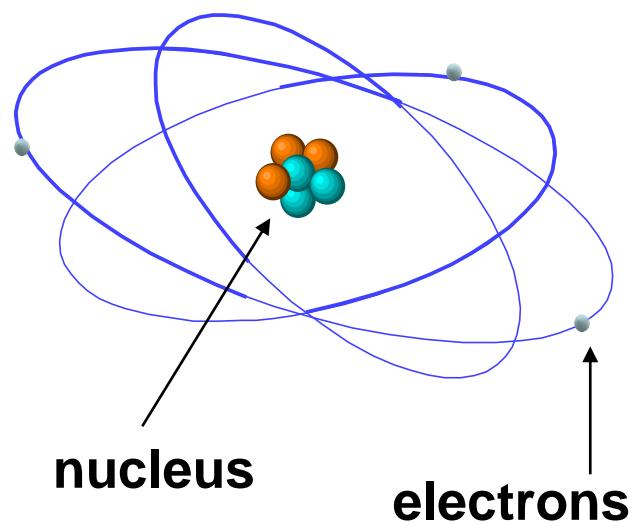
X symbol for the chemical element

General introduction

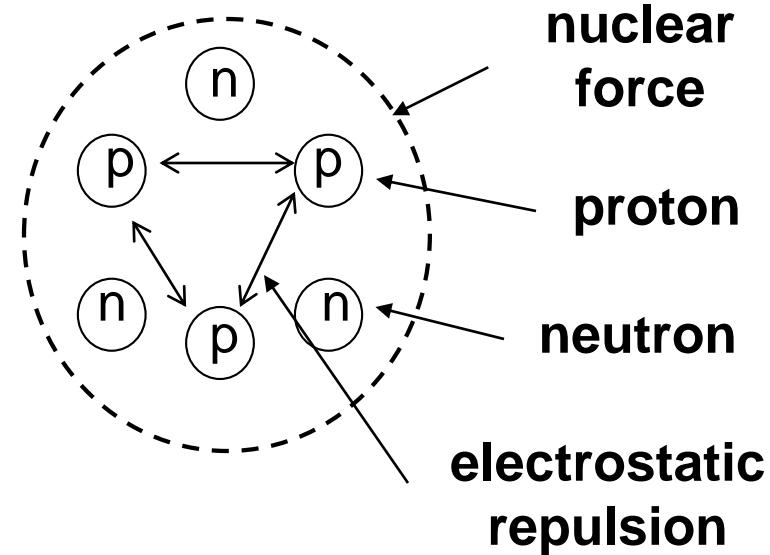
Fundamental physics of radiation

Nuclear forces and stability → Some atoms decay

Beryllium Atom $[{}^6\text{Be}]$



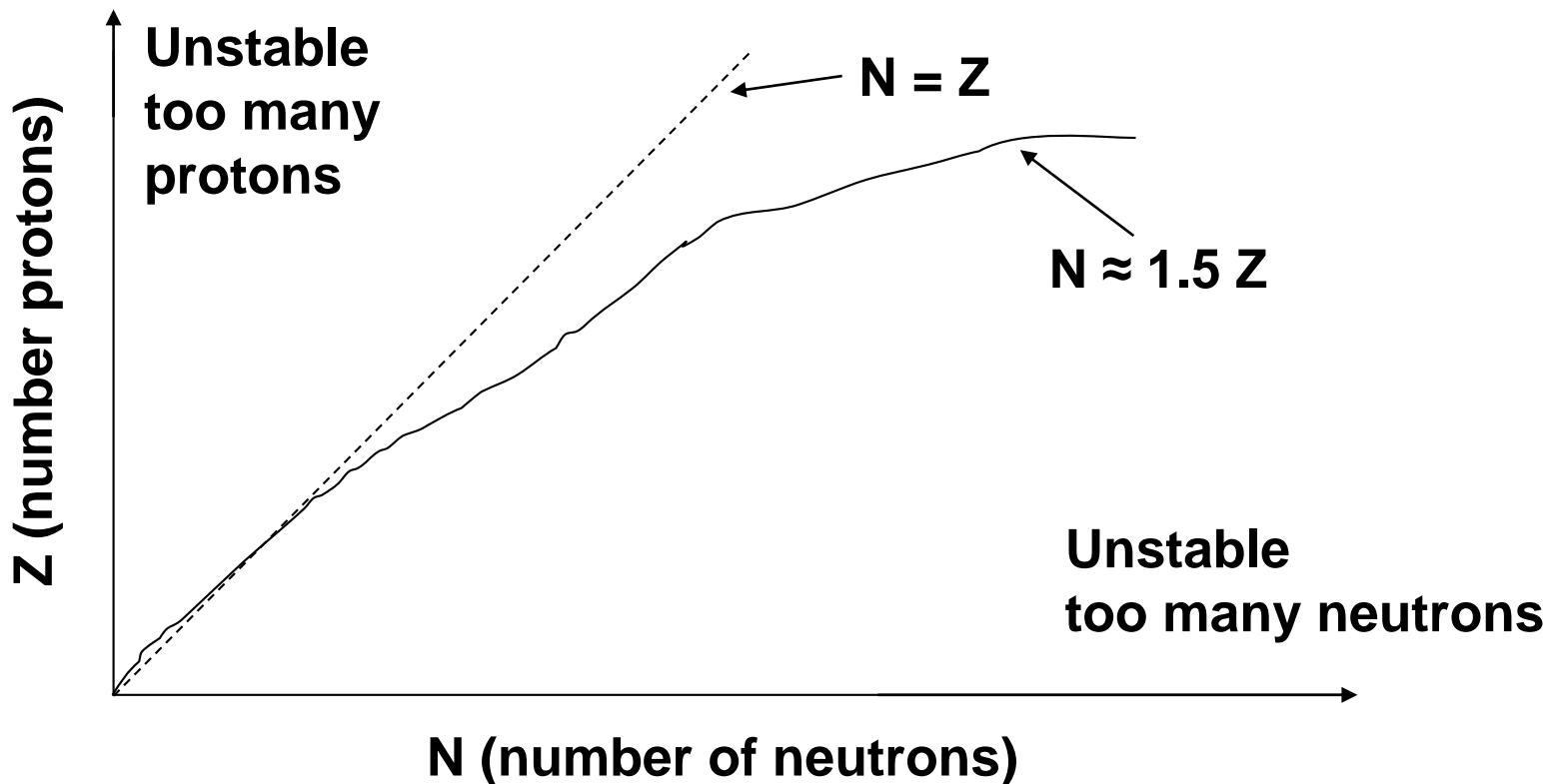
Forces acting on ${}^6\text{Be}$ nucleus



General introduction

Fundamental physics of radiation

Curve of nuclear stability



General introduction

Fundamental physics of radiation

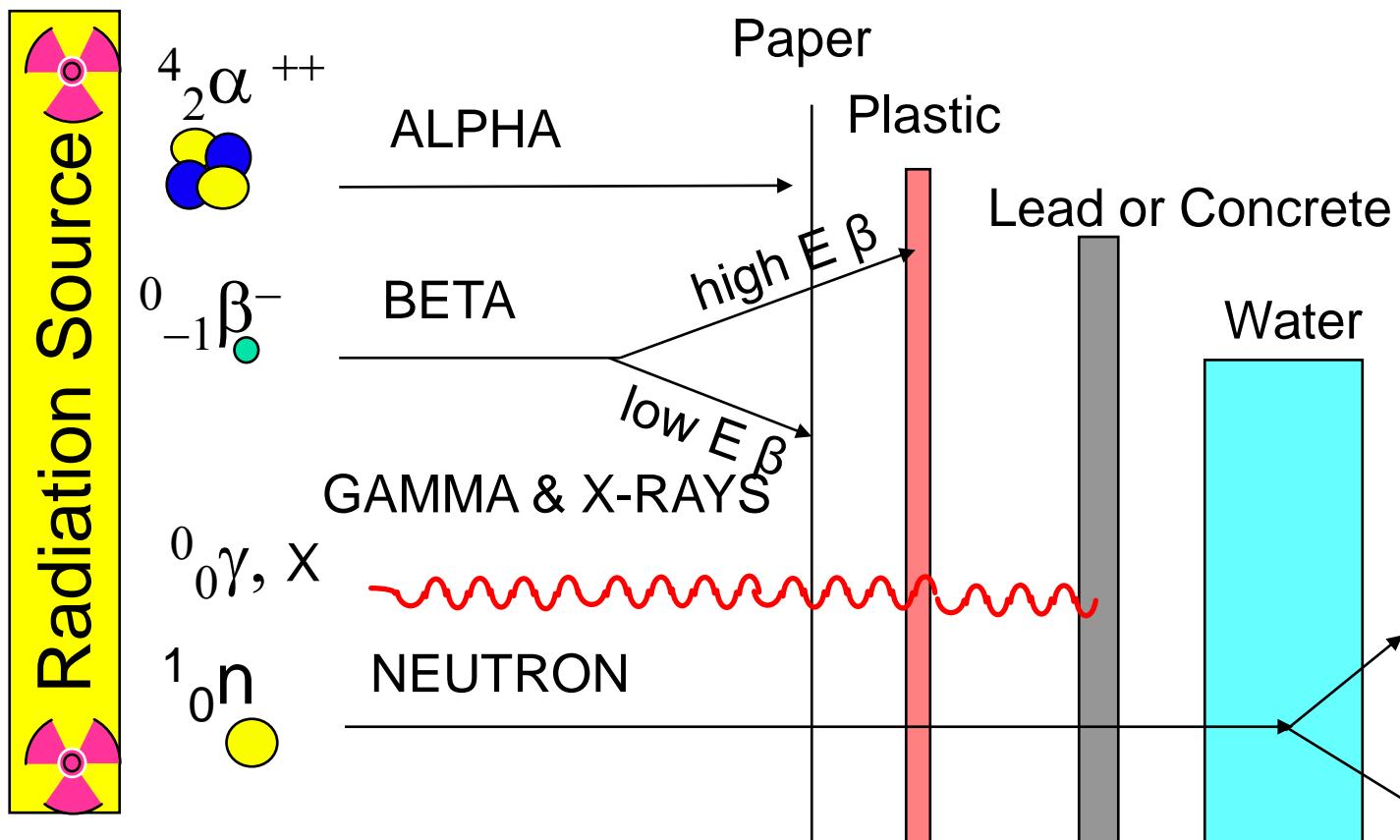
Principal Types of Ionizing Radiation

- **Particle (atomic or element)**
- **Alpha (α) – helium nucleus**
 - (from heavy nuclei [$Z \geq 82$])
- **Beta (β) – electron**
 - (Low Energy Beta < 250 keV)
 - (High Energy Beta > 250 keV)
- **Neutron (n) (uncharged)**
- **Electromagnetic**
 - Gamma (γ) - photon
 - X-ray (X) – photon

General introduction

Fundamental physics of radiation

Penetration abilities



General introduction

Fundamental physics of radiation

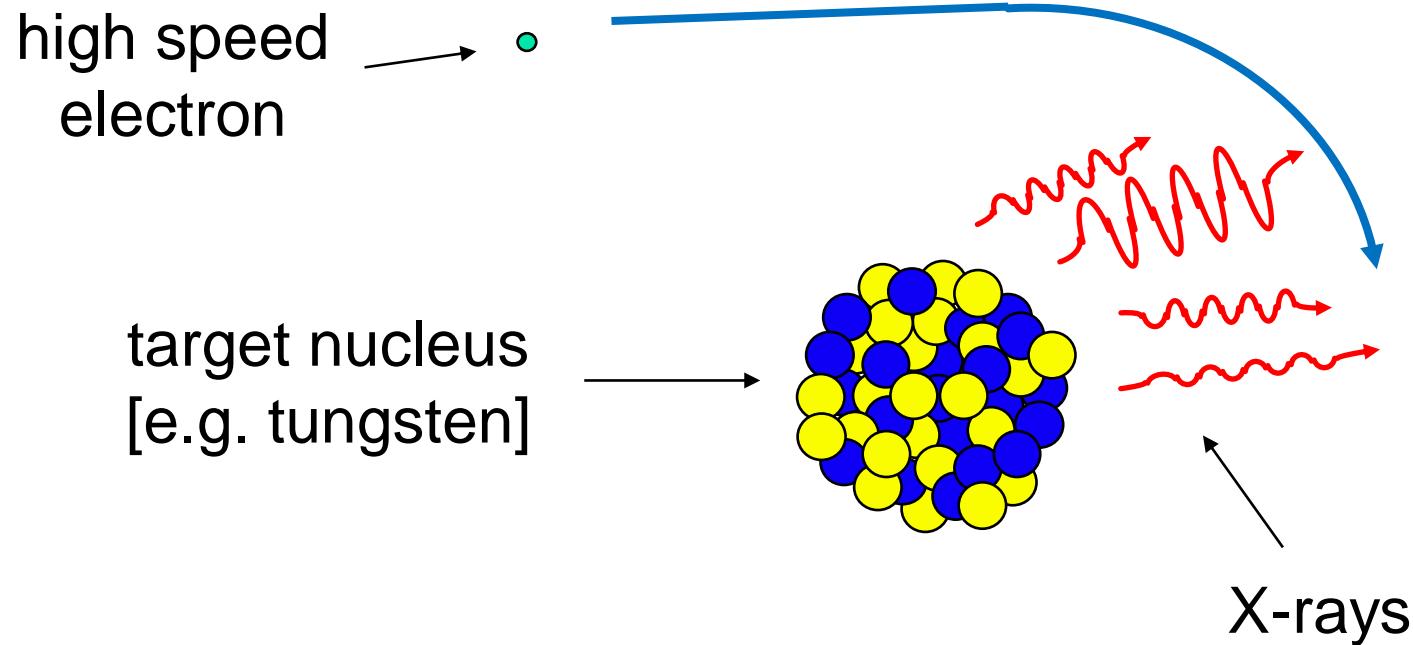
X-rays

BREMSSTRAHLUNG X-RAYS

CHARACTERISTIC X-RAYS

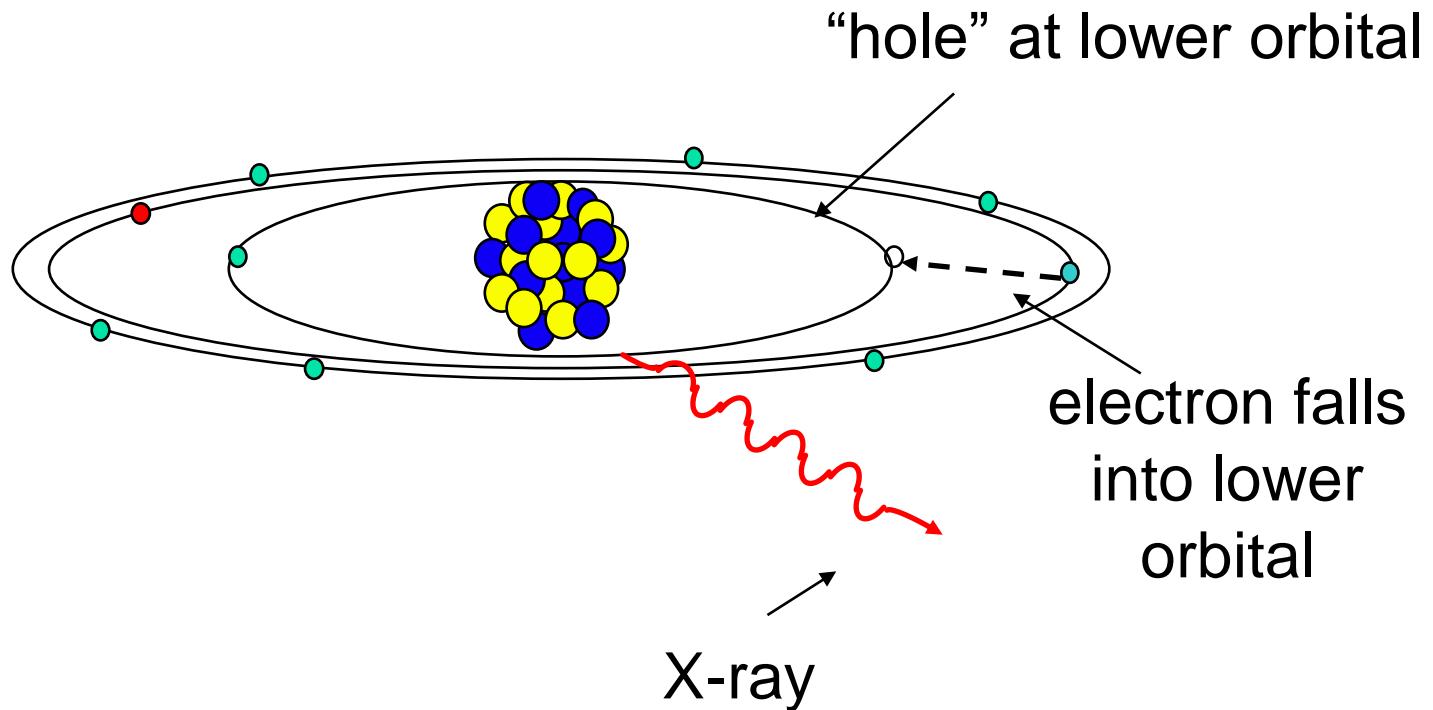
X-rays

BREMSSTRAHLUNG X-RAYS



X-rays

CHARACTERISTIC X-RAYS



General introduction

Fundamental physics of radiation

Nuclear equations

events that occur in the nucleus.

Alpha rays: $^{226}_{88} \text{Ra(s)} \rightarrow ^4_2 \text{He} + ^{222}_{86} \text{Rn(g)}$ They are balanced;
decay of Radium, found in many rocks and minerals. Radium decays to the gas Radon, which itself is radioactive. Radon, if breathed into the lungs, emits radioactive particles and is very likely to cause cancer.

Beta rays: $^{14}_6 \text{C(s)} \rightarrow ^{14}_7 \text{N} + ^0_{-1} \text{e}$

decay of carbon14. It is used in “carbon dating” of fossilized materials, and is also commonly used as a tracer for carbon in biochemical experiments.

Gamma rays: $^{131}_{53} \text{I} \rightarrow ^{131}_{54} \text{Ne} + ^0_{-1} \text{e} + ^0_0 \gamma$

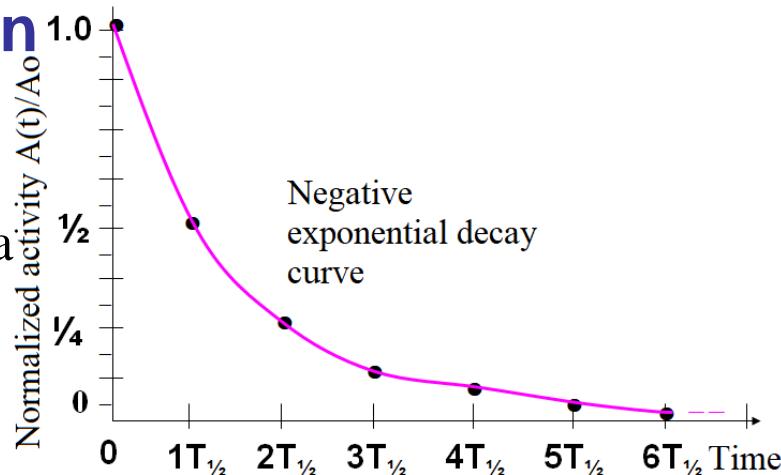
This describes decay of iodine-131. It is commonly used as a tracer for iodine in biochemical and physiological (thyroid) experiments.

General introduction

Fundamental physics of radiation

Half-life

Half time is the required time for the quantity of a radioactive material to be reduced to one-half its original value



Decay is a random process (or Activity, the amount of radioactive material) that follows an exponential curve.

Number of radioactive nuclei remaining after time (t): $A(t) = A_0 \cdot e^{(-\lambda t)}$

A_0 original number of atoms

$A(t)$ number remaining at time t

λ = decay constant (unique for each isotope; related to **probability** of decay)

General introduction

Fundamental physics of radiation

Specific activity (activity per unit mass or volume)

Inversely proportional to Half-Life

- Long half-life → low specific activity
- Short half-life → high specific activity

Example :

- **Pure Phosphorous 32 ($T_{1/2} = 15$ days)**
Sp. Act. = 286,000 Ci/g
- **Pure Carbon-14 ($T_{1/2} = 5730$ years)**
Sp. Act. = 4.5 Ci/g

General introduction

Fundamental physics of radiation

Radioactivity Units

- **curie (Ci): 3.7×10^{10} disintegration/second**
 - 1 Ci = a lot of activity [based on 1 g radium]
 - adult human has ~ 0.1 microcurie (μCi) ^{14}C
- **becquerel (Bq): 1 disintegration/second**
 - 1 Bq = tiny amount of activity [SI unit]
 - adult human has $\sim 3,700$ Bq ^{14}C
- $1 \mu\text{Ci} = 37 \text{ kBq} = 2.22 \times 10^6 \text{ dpm}$ [disintegration/minute]

General introduction

Fundamental physics of radiation

Interactions of Radiation with Matter

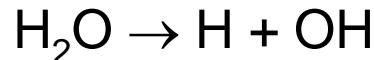
- **Ionization:** ejection of orbiting electrons from the atom
- **Excitation:** raising of orbital electrons to higher energy levels within the atom
- **Activation:** the process of making a material radioactive by bombardment with neutrons, protons, or other nuclear radiation

General introduction

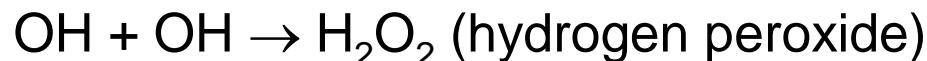
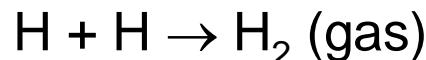
Fundamental physics of radiation

Main Chemical Effects in Tissue

- Primary reactions (within $\sim 10^{-10}$ seconds of passage of ionizing radiation)
 - Water molecule dissociates into free radicals:



- Secondary reactions (subsequent 10^{-5} seconds)



General introduction

Video to watch

https://www.youtube.com/watch?v=BWD9_EEacEg&t=352s

END